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THE IMPACT OF DIGITAL TRANSFORMATION ON ENTERPRISES' RESILIENCE: EVIDENCE FROM UKRAINE

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Abstract: *The research focuses on determining the impact of digitalization factors on the resilience of Ukraine's entrepreneurial sector. The main aim is to determine whether digitalization has a positive impact on the resilience of enterprises. The factors under research include the following: the availability of Internet access at Ukrainian enterprises, their e-commerce, the number of employees involved in research and development, and the share of enterprises that employ ICT specialists. The research methodology has two components: the use of a multifactor nonlinear regression model and the calculation of the proposed Index of Digital Penetration in the Ukrainian business sector. The results show that the most influential factors of digitalization are: the presence of employees specializing in ICT and e-commerce. Both factors make Ukrainian enterprises more resilient and adaptive to shocks. However, the results of the Digital Penetration Index emphasize the low level of digital transformation in Ukrainian enterprises, particularly limited automation and insufficient use of cloud computing and artificial intelligence technologies. The results of the study confirm that digitalization does enhance the resilience of Ukraine's entrepreneurial sector, but the low level of digital transformation underscores the need for legislative action to accelerate the development of advanced digital technologies. In order to benchmark the experience, the authors compare the use of digital technologies in Ukrainian and EU enterprises. The results of the research can be used to deepen the study of sectoral resilience, the experience of EU countries, and to provide recommendations for digital development of Ukraine.*

Keywords: *digital transformation, economic resilience, enterprises' resilience, digitalization*

INTRODUCTION

Enterprise resilience in the context of digitalization refers to the ability of businesses to integrate digital technologies to maintain competitiveness, ensure the continuity of business processes, and absorb shocks of various kinds. Two positive effects of digital technology adoption by the entrepreneurial sector can be identified. First, at the micro-level, it directly improves enterprise efficiency (positive correlation may result from process automation, better data management, and enhanced communication capabilities (Wang et al., 2023)). Summarizing existing theoretical research (Caputo et al., 2020; Bican & Brem, 2020; Legner et al., 2017), digitalization affects enterprise productivity through operational efficiency improvement, market expansion, better communication between business and household sectors, product diversification, and adaptability to a changing business environment. In addition, according to recent research, the development of a digital culture has a beneficial impact on the sustainable development of enterprises (Serafimova & Vasilev, 2024). Such

positive correlations contribute to enterprise resilience, as these conditions enable faster recovery following shock events.

The second assertion logically follows: digital technology adoption by the entrepreneurial sector enhances the resilience of the entire economic system. This can be attributed to the transformation of business models and the creation of new products (which increase economic diversification and, hence, adaptability); global market entry and revenue source diversification (which improve competitiveness and recovery capacity); and cost reduction through digitalization (which enhances the system's absorption capacity).

This paper aims to assess the impact of digitalization factors on the resilience of Ukraine's entrepreneurial sector. Research on the digitalization impact on enterprise resilience in Ukraine remains limited. While significant attention has been paid to economic security (Zinenko & Kobielieva, 2022; Hrinkevich et al., 2023; Ohrenych & Dibrova, 2023), innovation development, digitalization, and their implications for enterprise security (Popelo et al., 2023; Zubko et al., 2021; Kuzior et al., 2022; Dubyna et al., 2023), the concept of resilience and the direct impact of digital technologies are mostly explored theoretically. Therefore, expanding the research focus is appropriate.

This research addresses the following questions: (1) Can digitalization factors influence the resilience of Ukrainian enterprises? (2) If so, which factors have greater or lesser impacts? (3) If digital technologies affect enterprise resilience, what is the current level of digital technology penetration in Ukraine's entrepreneurial sector?

METHODS

The research consists of two quantitative components: (1) the application of a nonlinear regression model to assess the impact of digitalization on enterprise resilience and (2) the calculation of the Digital Technology Penetration Index for Ukraine's entrepreneurial sector.

The assessment of the impact of digitalization factors on enterprise resilience was conducted using mathematical modeling, particularly a multifactor nonlinear regression model. This method is widely employed by both Ukrainian (for assessing the impact of digitalization on economic security (Zubko et al., 2021)) and international researchers (for assessing the impact of digital technologies on urban resilience (Shi et al., 2023), the influence of digital transformation on SME resilience (Omoush et al., 2023), and the effect of innovation on urban disaster resilience (Samarakkody et al., 2023)). Several key theoretical and methodological considerations justify the choice of a nonlinear regression model: the influence of digitalization factors is often nonlinear due to varying intensities and speeds of enterprise adaptation to digital changes, and complementary or substitution effects are better evaluated through nonlinear models.

The calculation of the Index involves the following steps:

1. Selection of indicators and data collection. Indicators were chosen to reflect the level of digital technology adoption and use by national economy enterprises (Table 4).

2. Definition of threshold values. Thresholds were developed considering Ukraine's economic specifics (size, development dynamics, historical context, strategic digitalization goals), as well as the experience of EU countries.
3. Data normalization according to threshold values. If an indicator value exceeds the threshold, it is normalized to 1; otherwise, it is normalized to 0.
4. Calculation of digital technology penetration:

$$I_m = \frac{\Sigma N = 1}{\Sigma N_x} \times 100\%$$

where I_m is an integral indicator of the m-th sector of the economy, where m = (1, 2, 3)
Nx=1 — is the number of indicators whose normalized value is 1;
Nx — number of indicators.

DATA

The research process and results depend entirely on the availability of statistical data. The assessment of Ukraine's digital environment used data from the State Statistics Service of Ukraine and official EU statistics, as well as international indices (Global Innovation Index and Frontier Technology Readiness Index). Due to the ongoing war initiated by Russia, data collection has been suspended or restricted, limiting the research scope. The quantitative assessment took into account only those time periods that had the most complete statistical data. For missing indicators, the latest available data were used.

RESULTS

To build this model, it is necessary to define the dependent variable (Y) and independent variables (X) (Table 1). Accordingly, within the model, the dependent variable will be an indicator that assesses the economic resilience of the entrepreneurial sector. The independent variables are indicators that will reflect the factors of digitalization's impact on resilience.

As a dependent variable, the indicator of value added by production costs of economic entities was chosen. We believe that the selected indicator successfully demonstrates the resilience of the sector: value added by production costs actually means the ability of enterprises to create new economic value. Even in the face of shocks, enterprises with a stable level of value added are better able to maintain their operations and ensure financial independence.

The indicators that will serve as independent variables and reflect the impact of digitalization on economic resilience are: the number of enterprises with access to the Internet; the volume of products (goods, services) sold by enterprises derived from e-commerce; the number of employees involved in research and development; and the share of enterprises with ICT specialists.

In addition, we believe that it would be appropriate to assess the use of CRM systems by enterprises of the national economy (as this is a direct reflection of automation processes) and the state of cybersecurity, but currently there is no statistical data for the period under research. It should also be noted that due to the lack of statistical data for the share of the

number of enterprises that employ ICT specialists (statistical data are not available for 2020 and 2022), the model may contain a certain percentage of uncertainty - for the purpose of the assessment, the indicators for 2020 and 2022 were projected based on the growth (decline) rates of previous years.

Table 1. *Initial data for assessing the impact of digitalization on value added by economic entities' expenditures*

	Value added by production costs of economic entities	The number of employees involved in research and development	The number of enterprises with access to the Internet	The volume of products (goods, services) sold by enterprises derived from e-commerce	The share of enterprises with ICT specialists
Year	Y	X1	X2	X3	X4
2018	**2640886379,2**	88128	43303	228 035 634,70	22,3
2019	**3121256476,2**	79262	43785	292 731 939,10	21,6
2020	**3294768464,7**	78860	44271	364 571 488,00	20,9
2021	**4594232280,4**	68808	44508	435 909 793,90	21,7
2022	**3947735837,3**	53221	42785	465 316 898,70	17,7
2023	**4838907049,6**	58567	34204	547 590 249,30	17,7

Source: Website of the State Statistics Service of Ukraine, 2022

Calculations and model building were based on a regression model in Excel. The level of reliability is defined as 0.95 - the boundaries of the confidence interval for each regression coefficient cover the true value with a probability of 95%. Considering the upper limit of the confidence interval for each of the coefficients, the model is as follows:

$$\check{Y} = -49274{,}9X_1 - 72464{,}9X_2 + 6{,}5X_3 + 433463774{,}7X_4 - 1029872880$$

The coefficient of determination R^2 is quite high and amounts to 0.999. Thus, the variation of value added by the costs of economic entities is 99% determined by the variation of the proposed factors, but there are 0.1% that are unaccounted for.

These results allow us to assess the adequacy of the model. According to the Fisher's test of adequacy, the obtained F-value (0.02) is lower than the significance level (0.05), so since $F < a$, we can say that the model is generally statistically significant and adequate. We can assess the adequacy and statistical significance of each coefficient separately by using the critical t value from the Student's statistical table. If the critical significance level is $\alpha = 0.05$ and the degree of freedom is n-m=2, the critical value is 2.920. As can be seen from the results of the t-test (Table 2), all available coefficients are greater than the critical value. This indicates that they are not statistically significant. Therefore, we consider it necessary to use a different type of model to evaluate the selected indicators.

Table 2. *Calculations of a multifactor linear model*

	Coefficients	**t-statistics**	**p-value**	**R-square**	**The significance of F**
Y	-1029872879,60175	-2,33445888668255	0,257650973	0,999	0,0240
X1	-49274,90302	-10,8441748720604	0,058540589		
X2	-72464,89698	-10,5163655881444	0,060354627		
X3	6,54706318666723	17,1301999848115	0,037121463		
X4	433463774,656223	19,6914621593524	0,032301987		

Source: compiled by the authors

From now on, we will use a power function with its transformation to a linear form as a result of logarithmizing. The function will have the following form:

$$lnY = lnA + \alpha \times lnX_1 + \beta \times lnX_2 + \gamma \times lnX_3 + \delta \times lnX_4$$

The calculations were performed by building a regression model in Excel, and the results are as follows: $\grave{A} = 10.33$, $\alpha = -1{,}02$, $\beta = -0{,}9$, $\gamma = 0{,}61$, $\delta = 2{,}39$.

Accordingly, taking into account the logarithmization of the coefficients, we have the following form of the function:

$$Y_{calc} = \exp(10{,}33) \times X_1^{-1{,}02} \times X_2^{-0{,}9} \times X_3^{0{,}61} \times X_4^{2{,}39}$$

The final result after calculating the exponential function:

$$Y_{calc} = 30{,}638.1 \times X_1^{-1{,}02} \times X_2^{-0{,}9} \times X_3^{0{,}61} \times X_4^{2{,}39}$$

The coefficient of determination R^2 of the newly created model remained at the same level - 0.99, which still indicates a high influence of the factors considered. We can also assess the adequacy of the model, in particular, using Fisher's criteria. For this purpose, we will use the result of the F-value for the built model and the tabulated F-value for the significance level of 0.05. To select the correct table value, we also took into account the number of independent variables (4) and the total number of observations (6) minus the number of parameters. Accordingly, $F_{table} = 7.7$, $F_{calc} = 3354{,}08$; $F_{calc} > F_{table}$. We can conclude that the model is reliable, all factors have an impact on the dependent variable (p-value in Table 3).

Table 3. *Results of calculations using a power function with logarithmization*

	Coefficients	**t-statistics**	**p-value**	**R-square**	**The significance of F**
Y	10,32814803	28,62656837	0,022229734	0,999	0,012949335
X1	-1,015903715	-24,22316748	0,026266527		
X2	-0,903507143	-26,19640569	0,024290005		
X3	0,607733673	39,84619939	0,015973573		
X4	2,392693185	35,46667481	0,017945047		

Source: compiled by the authors

Thus, according to the results of the calculations, the factor of the availability of ICT employees at enterprises has the greatest impact on the entrepreneurial sector's resilience. There are several reasons for this: first of all, enterprises with ICT specialists are able to demonstrate

greater preparedness for digital threats (cyberattacks or NDA data leaks), which directly affects their ability to maintain functionality during economic shocks. In addition, there is a possibility of greater flexibility and technical competitiveness of the enterprise: the presence of ICT specialists in the enterprise allows for the introduction of modern digital technologies, and thus, increases the efficiency of operational processes.

The results also show that e-commerce has a significant impact, which can be explained accordingly:

1. E-commerce actually eliminates most of the barriers to doing business: physical interaction between consumer and seller is replaced by digital communication (which is faster and more affordable), and it is easier to expand the market - it becomes possible to compete not only in the national but also in the international market, with a positive result of diversifying the customer base.
2. Another positive effect of e-commerce is the reduction of transaction costs: enterprises can increase their profitability by reducing the cost of renting premises, logistics, etc. However, of course, there is also the possibility that costs will be incurred for maintaining a website, CRM systems to automate customer interaction, and the development of digital marketing campaigns.

The impact of Internet access at the enterprise and the number of employees involved in R&D is also statistically significant. However, it should be noted that the effectiveness of these two factors is difficult to assess in the short term (which is why their impact is negative in the current situation, see Table 3). For example, the effect of R&D can be traced conditionally in 5-10 years, and the effect of using the Internet connection is also not immediately noticeable (or its significance is not so great). In order to comprehensively assess the level of digital transformation of Ukraine's entrepreneurial sector, we propose to consider the developed Digital Penetration Index (Table 4).

Table 4. *Input data for the calculation of the Digital Penetration Index in the entrepreneurial sector of Ukraine*

№	Indicator	Threshold value	2022
1	Share of enterprises engaged in e-commerce in the total number of enterprises, %.	≥ 22	6.1
2	Share of the number of enterprises using fixed Internet access in the total number of enterprises, %.	≥ 90	61.8
3	Share of the number of enterprises applying ICT security measures in the enterprise's information and communication systems in the total number of enterprises, %.	≥ 90	73.2*
4	Share of enterprises purchasing cloud computing services in the total number of enterprises, %.	≥ 40	9,8
5	Exports of ICT services, USD billion	≥ 6.5	7.52

6	Share of the number of enterprises that faced problems due to ICT security incidents in the total number of enterprises, %.	≥ 15	24.7
7	Share of the employed population in the ICT sector in the total number of employed people, %	≥ 4	1.9**
8	Share of the number of enterprises using artificial intelligence technologies in the total number of enterprises, %.	≥ 6	5.4
9	Global Innovation Index	≥ 30	32,3
10	Frontier Technology Readiness Index	≥ 0.61	0.59

Source: Website of the State Statistics Service of Ukraine, Global Innovation Index (GII), Frontier technology readiness index

** — statistical data for 2023;*

*** — statistical data for 2021;*

After analyzing the available statistics, we can calculate the level of digital penetration in Ukraine's entrepreneurial sector using the following formula:

$$I_m = \frac{\Sigma N = 1}{\Sigma N_x} \times 100\%$$

Thus, the calculation is as follows:

$$I_1 = \frac{3}{10} \times 100\% = 30\%$$

The level of digital technology penetration in Ukraine's business sector is 30%. According to the proposed assessment scale (Table 5), this level is low, which means minimal adoption of digital technologies. Business processes are mostly performed manually, but there is a small percentage of automation. The level of digital skills of employees is also low and needs to be significantly improved.

Table 5

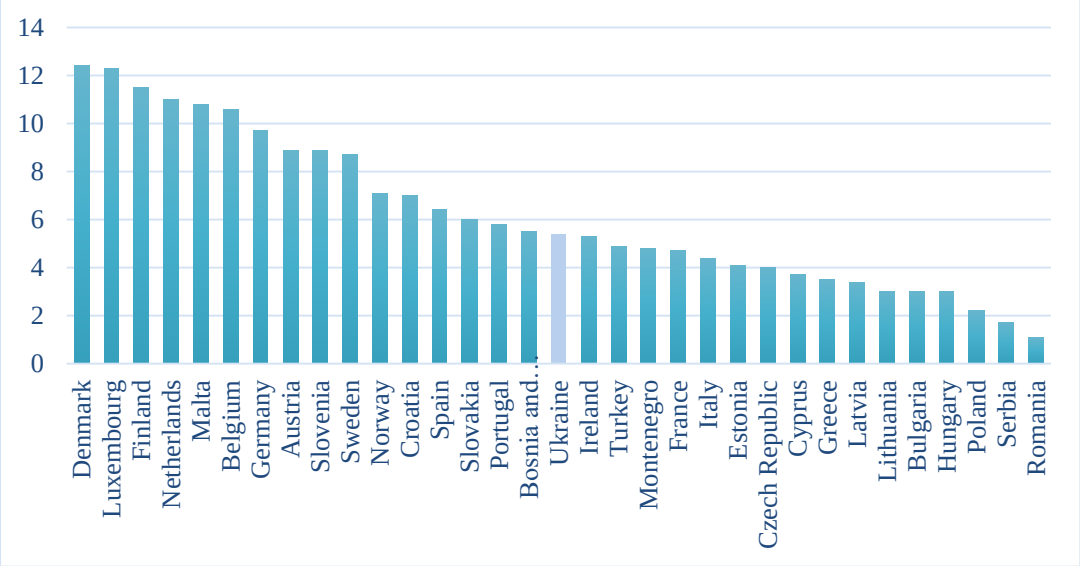
Digital penetration scale	Penetration level	Meaning
100-80%	High	Business operations are fully dependent on digital technologies. Business processes are automated, artificial intelligence, cloud computing, and IoT are used. Employees' digital skills are at a high level.
80-60%	Sufficient	Digital technologies are actively used in operations, but not to the fullest extent. Thus, business process automation is selective and digital tools are partially used. The level of digital skills of employees is average.
60-40%	Moderate	Digital technologies are used only for certain business processes, automation is fragmented, with limited use of digital tools. There is a need to improve the digital skills of employees.

40-20%	Low	Digital technologies are implemented at a minimal level. Business processes are mostly performed manually, but there is a small percentage of automation and use of digital tools. Low level of digital skills of employees.
20-0%	Extremely low	Digital technologies are hardly used, and enterprises are dominated by "traditional" approaches to doing business, without significant automation. The level of digital skills among employees is too low.

Source: compiled by the authors

Statistical analysis shows that the weakest points of Ukraine's entrepreneurial sector are indicators related to automation (in particular, the use of AI and cloud computing in enterprises). Compared to EU countries, the share of enterprises using AI technologies in Ukraine is not very high - 5.4% (statistical data of enterprises with 10 to 49 employees) (Website of the State Statistics Service of Ukraine, 2022), while the average value in EU countries is 6.2% (Eurostat, 2022). It is also worth noting that a characteristic feature of the national economy is the invariance of this indicator depending on the size of the enterprise: the share of large enterprises using AI technologies in Ukraine is 5.2% (which is 0.2% less than the same share in the context of small enterprises). On the contrary, compared to small enterprises, large enterprises in the EU use AI technologies more often - 14.5% (Eurostat, 2022) across the EU. Obviously, the conditions of a full-scale war somewhat limit the introduction of innovative technologies in enterprises, but as a rule, large enterprises are more resilient and adaptive to shocks, so it is surprising that they fund AI technologies less.

Figure 1. *Share of enterprises using AI technologies in Ukraine and EU countries*



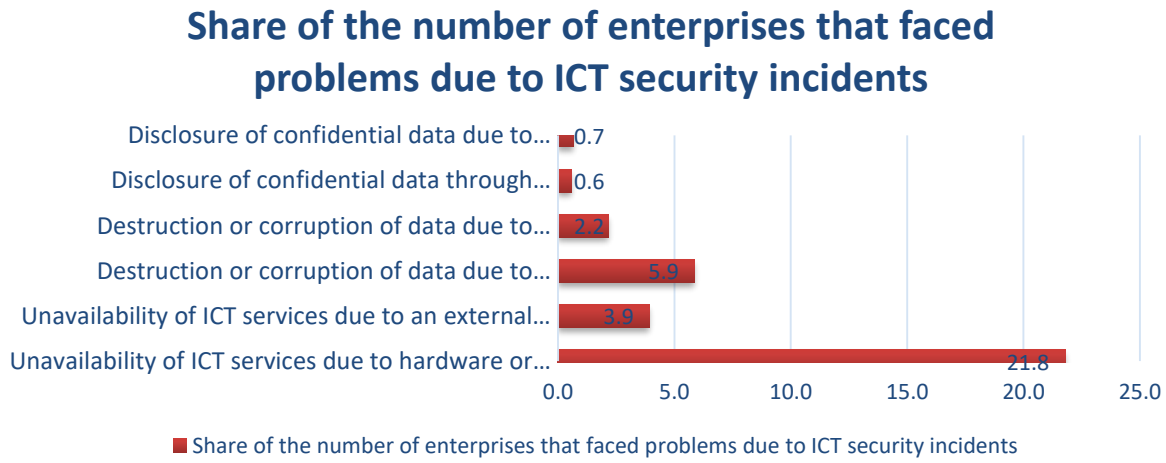
*Source: compiled on the basis of (*Eurostat, 2022; Website of the State Statistics Service of Ukraine, 2022)

The share of the number of enterprises that purchase and use cloud computing services is also low compared to EU enterprises. While the average value for the EU countries is 42.5% (2023), only 9.8% of Ukrainian enterprises take advantage of cloud computing.

Internet access also needs to be improved. In 2023, 80.8% of Ukrainian enterprises had access to a fixed-line Internet connection, which is 19% more than in 2022. However, under ideal conditions, this figure should reach at least 90%, as the experience of EU countries shows. We assume that this may be due to infrastructure constraints: areas with low population density have a lower number of fixed Internet access lines, where providers are not economically interested in laying fixed networks. In addition, damage to or destruction of infrastructure as a result of hostilities, especially in frontline areas, significantly complicates access to the fixed Internet. It should not be forgotten that enterprises with unstable income tend to use an alternative network - the mobile Internet.

The level of digital security in the business sector can be indicated by the share of enterprises that use ICT security measures. According to statistics, in 2023, there were not too many ICT incidents among Ukrainian enterprises - the share of the number of enterprises that faced problems was 24.7% (in the total number of enterprises) (Website of the State Statistics Service of Ukraine, 2022). The most vulnerable economic activities are: manufacturing (production of coke and petroleum products, basic pharmaceutical products and pharmaceuticals); wholesale and retail trade; computer programming, consulting and related activities; provision of information services; travel agencies, travel operators, provision of other reservation services and related activities.

Figure 2. *Types of ICT incidents among Ukrainian enterprises*



Source: compiled on the basis of (Eurostat, 2022; Website of the State Statistics Service of Ukraine, 2022)

At the same time, security measures are used by the vast majority of enterprises in the national economy - 73.2% in 2023. The most commonly used security measures include strong password authentication (66.3%) (unfortunately, more secure authentication methods, such as biometric methods or a combination of two authentication methods, are used much less frequently), backing up data to a secure location (52.7%), controlling network access (44.6%), encrypting data, documents, or email (23%), and VPN (21.4%). However, these figures are

significantly lower than in the EU, where 92% of businesses use at least one security measure on average. The most popular in the EU are password authentication (82%), backups (78%), and network access control (65%).

The strength of the digital transformation process of Ukraine's business sector is the size of ICT exports and the resilience of the IT sector as a whole. Even though the national economy's ICT services exports have a positive upward trend, 2023 was the first year when the value of this indicator decreased. According to the World Bank, in 2023, Ukraine's ICT services exports amounted to USD 6.8 billion. USD (for comparison, in 2022, the value of the indicator was 7.52 billion USD, which is 0.72 billion USD less. USD, which is 0.72 billion more). It is noted that the reason for this may be a slowdown in economic growth in global markets. The countries from which the revenue from ICT exports comes are: USA (USD 2,667 million), Malta (USD 567 million), Great Britain (USD 535 million), Cyprus (USD 362 million), Israel (USD 293 million), Germany (USD 275 million), and Switzerland (USD 274 million). All of these countries are currently experiencing a recession, and the demand for ICT services is not as high as it was during COVID-19. Local reasons are also worth highlighting: increased investment risks due to a full-scale invasion and the mobilization process, which affects the number of IT professionals.

DISCUSSIONS

Thus, the use of a quantitative approach, specifically building a nonlinear regression model, enabled the identification of the impact of digitalization factors on the resilience of Ukraine’s entrepreneurial sector. According to the results, the most significant influence on value added by production costs of economic entities stems from the presence of ICT specialists in enterprises and the adoption of e-commerce. The presence of ICT specialists directly affects economic resilience by ensuring productivity and adaptability. Employees with ICT skills and, accordingly, a high level of digital culture, increase resilience, strengthening the enterprise's innovation potential, flexibility to change and competitiveness (Serafimova & Vasilev, 2024). E-commerce, in turn, is no less important for enterprise resilience. Enterprises that use e-commerce as a sales channel can respond more swiftly to demand fluctuations, scale sales, and optimize transaction costs. These factors most significantly contribute to enhancing: (1) economic efficiency, (2) digital adaptability, and (3) resilience to external shocks.

However, the results of the Digital Technology Penetration Index for Ukraine's entrepreneurial sector indicate that processes related to e-commerce and the employment of ICT specialists remain among the weak points of the national economy, as their values fall below threshold levels. This undoubtedly limits the resilience of Ukraine’s entrepreneurial sector. Firstly, there is a substantial negative impact on adaptability—in the case of macroeconomic or geopolitical shocks (such as the onset of the full-scale invasion), enterprises lacking digital sales channels or automated processes are less able to adapt to changes. Secondly, this contributes to reduced competitiveness across the economy, as a low percentage of ICT specialists constrains the adoption of advanced digital technologies.

Despite the comprehensive analysis, the research has certain limitations. The most significant limitation relates to the use of statistical data. It would have been preferable to analyze a longer time period, thereby obtaining more regression observations, which would have greatly increased the accuracy of the results. However, official data for some selected indicators were unavailable. This affected both the time frame for the regression model and the calculation of the Digital Technology Penetration Index. As noted, the Index was calculated only for 2022, which considerably limits the ability to draw precise conclusions. Nevertheless, this period provided the most comprehensive set of statistical data for the selected indicators.

The choice of threshold values for the Index indicators is also a matter of discussion. In most cases, their development is based on a quantitative method, i.e., calculating the median value among the results of the European Union countries, but certain qualitative characteristics were also taken into account (such as the historical context of Ukraine's economic development, the pace of digitalization and its strategic vision in the country, current shocks, etc.), which indicates a degree of subjectivity in this approach.

Considering the results and limitations, the study has the potential for further development. The publication of official statistics for more specific indicators (e.g., cybersecurity, cloud computing, and AI) is becoming regular, so it is expected that it will be possible to assess longer time periods in the future and expand the analysis of the Index indicators, which will make the analysis more accurate and comprehensive. Additionally, sectoral analysis warrants attention. Understanding that digitalization factors do have a positive impact on the resilience of enterprises, the question arises as to which industries are more affected and whether digitalization is a key factor for all industries. In this regard, it would be valuable to compare the most significant sectors contributing to Ukraine’s GDP and assess the impact of digitalization factors on them.

Also, since the research is partly based on a comparison of Ukraine's experience with the EU countries, there is a need for a broader analysis: a comparison of regression analysis of the impact of digitalization on EU and Ukrainian enterprises, and a study of the experience of European countries. Although the results of the study and the developed Index are adapted to the economic conditions of Ukraine and there is no direct generalization of the study, it is possible to adapt the methodology and structure of the research to other countries.

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